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Utilization of toxic marine invaders in the development of low-loss microwave devices

Düşük kayıplı mikrodalga cihazlarının geliştirilmesinde zehirli deniz istilacılarının kullanımı

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Abstract

This research paper presents constitutive parameters of toxic marine invaders (*Diadema setosum*) and offers the availability of materials from these invaders for microwave applications. Two different powder form of these invaders were prepared and calcined at different temperatures. These biomaterials have been obtained for grinding shell and spines of sea urchin were turned into powder. The constitutive parameters as complex dielectric constants of these classified biomaterials have been investigated in 3.2-20 GHz frequency range with open-ended coaxial probe method. Measured results show that these biomaterials have a potential usage area in microwave range are mentioned firstly in literature. Measured complex permittivity properties of samples of shell and spines of invasive long-spined sea urchin have demonstrated that samples can be utilized in development of high-quality microwave radomes with high impedance matching to air and low loss microwave substrates.

Keywords: *Diadema setosum*, Microwave electronics, Microwave substrates, Radome

Öz

Bu araştırma makalesi, mikrodalga uygulamaları için zehirli deniz istilacılarının (*Diadema setosum*) mikrodalga parametrelerini incelemektedir ve bu istilacılardan elde edilen malzemelerin mikrodalga uygulamaları için kullanılabilirliğini sunmaktadır. Bu istilacı canlılardan iki farklı toz formu hazırlanmış ve farklı sıcaklıklarda kalsine edilmiştir. Bu biyomalzemeler denizkestanesi *D. setosum*'un kabuk ve dikenlerinin öğütülmesi ile elde edilmiş ve toz haline getirilmiştir. Bu sınıflandırılmış biyomalzemelerin dielektrik sabiti olan yapısal parametreleri, açık uçlu koaksiyel prob yöntemi ile 3,2-20GHz frekans aralığında incelenmiştir. Ölçüm sonuçları ile desteklenen bu çalışma, mikrodalga frekans aralığında potansiyel bir kullanım alanına sahip olan bu biyomateryallerin literatürde ilk kez bahsedildiğini göstermektedir. İstilacı uzun dikenli denizkestanesinin kabuk ve diken örneklerinin ölçülen karmaşık geçirgenlik özellikleri, örneklerin havaya ve düşük kayıplı mikrodalga substratlara uyan yüksek empedanslı yüksek kaliteli mikrodalga radomların geliştirilmesinde kullanılabileceğini göstermiştir.

Anahtar kelimeler: *Diadema setosum*, Mikrodalga elektronik, Mikrodalga substrat, Radom

1 Introduction

The lack of prey pressure on marine animals with no economic value and their rapid spread have negative effects on the ecosystem and native (endemic) species in the marine environment in which they live [1,2]. Especially in the last decade, the Mediterranean Sea is a good example of this invasive species due to the rapid increase. Entry of invasive species to the Mediterranean Sea is mainly by ship transportation through the Suez Canal and the Strait of Gibraltar. Species entering via the Suez Canal are called Lessepsian species, and 80 fish and 123 invertebrates have been entered so far [3]. Among the invasive fish species, especially puffer fish are harmful invaders that have spread throughout the Mediterranean within 20 years [4]. Similarly, the lionfish (*P. miles*) spreads rapidly throughout the Mediterranean Sea [5]. One of the invertebrate species that enter the Mediterranean Sea and have a serious potential for invasion is the long-spined sea urchin *Diadema setosum* [6]. The invasive long-spined sea urchin (*D. setosum*) is a species of Indo-Pacific origin and it is widely distributed in the Red Sea (Gulf of Suez, Gulf of Aqaba, Northern and Southern Red Sea), east coast of Africa, Japan and Australia [7]. It was reported for the first time on the Turkish coasts in 2006 on the Kas Peninsula of Antalya, and then on the coasts of the Iskenderun Bay, Aegean Sea and Marmara Sea [8-10]. *D. setosum* (Figure 1) reaches large sizes due to its unique feeding habits and reproductive behaviors and poses a great threat to endemic species with the increase in its population.

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Due to its morphological structure (like long spines), sea urchin damages the fishing gear and fishing activities. In addition, its long, black, and toxic spines cause adverse effects such as painful injury, swelling and redness if it penetrates the human skin.

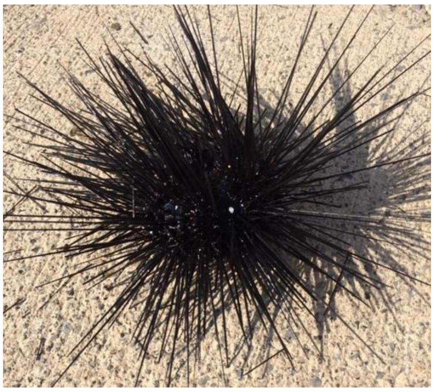

Figure 1. *Diadema setosum* (original picture).

In this study, the shell (Shell-T) and spines (Spine-S) of the invasive sea urchin were ground without any treatment. Powdered shell and spines and these two powder samples were calcined at different temperatures. In this research, biomaterials have been obtained because of grinding the shell and spines of sea urchin were turned into powder. The powder samples were classified into different samples after being subjected to calcination at different temperatures. The electrical properties of these classified biomaterials have been investigated in the microwave frequency range with the open-ended coaxial probe method. The investigation of electromagnetic properties of biomaterials obtained from sea urchins in the microwave frequency range of 3.2-20 GHz have been carried out for the first time in the literature. According to the results of the measurements, potential usage areas in the microwave frequency region are also mentioned for the first time in the literature. The measured electrical properties of the samples obtained from shell and spines of invasive long-spined sea urchin have demonstrated that the samples can be utilized in development of high-quality microwave radomes with high impedance matching to air and low loss microwave substrates to design microwave circuits.

Hence, this invasive marine invertebrate, which can be used in related fields and is not consumed in our country, will be brought to the country's economy as a biomaterial with high economic value.

2 Material and methods

Invasive sea urchin (*Diadema setosum*) used in the production of biomaterials has been collected from the Iskenderun Bay. Sea urchins brought to the laboratory were first trimmed and separated from their spines (Figure 2a). Sea urchin shells (testa) were divided into two with a pair of scissors and all soft tissues were removed (Figures 2b and 2c). Afterwards, the shell and spines were thoroughly washed with tap water and then with bidistilled water and dried in an oven at 70 °C for 24 hours (Figures 2b and 2c). The dried biomaterials were ground and sieved with the help of a grinder (Figures 2d and 2e).

Figure 2. Trimmed and separated form of spines of sea urchins (a) shells (b) and spines (c) divided into two with a pair of scissors of sea urchin, washed with tap water and then with bidistilled water and dried in an oven at 70 °C for 24 hours of the shell (d) and spines (e)

Some of the dried shell and spine powders were calcined in a chamber type furnace (Proterm PLF series), each sample was calcined at 4 different temperatures (600, 800, 1000 and 1200 °C) for 1 hour at a heating rate of 5 °C/min. Moreover, the materials were left to dry in a desiccator at room temperature. Immediately afterwards, the shell powder biomaterial was labeled T, T600, T800, T1000, and T1200, and the spine powder biomaterials S, S600, S800, S1000, and S1200 (Figures 3a and b). It was kept in closed falcon tubes to be used in experiments to measure electromagnetic properties in microwave analysis. After these processes, microwave analysis has been started.

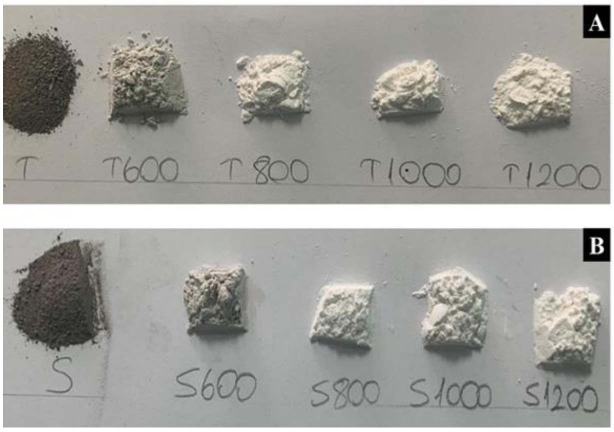

Figure 3. The prepared samples of shell (a) and spine (b) powders dried with various temperature.

2.1. Microwave analysis

Prepared shell and spine powder samples have been characterized in microwave laboratory and the complex permittivity parameters of each sample are obtained by using dielectric probe kit and an Agilent PNLA Vector Network Analyser (VNA) as shown in Figure 4a. Hence, the utilization potential in microwave applications of the samples have been investigated in a wide frequency range. Although various techniques can be used to obtain the relative permittivity of the samples such as Nicolson Ross Weir method, open ended coaxial prob method has been selected due to the samples in the form of powder.
The dielectric parameters of a material is expressed in terms of the relative permittivity as [11];

$$\varepsilon = \frac{P}{\varepsilon_0 E} + 1 \tag{1}$$

where P is the polarization to the electrical field strength and E of an external electric field. The relative complex dielectric constant of the sample is [12];

$$\varepsilon = \varepsilon' - j\varepsilon'' \tag{2}$$

The loss tangent is as follow [12];

$$tan\delta = \frac{\varepsilon''}{\varepsilon'} \tag{3}$$

Before the measurement, a calibration process has been completed to minimize the losses, noises and interferences caused by laboratory conditions. Besides, the measurement frequency region has been chosen between 1 GHz and 20 GHz which is the maximum dielectric parameter band of the utilized VNA. In the calibration process, the dielectric probe kit has been tested under three conditions. Firstly, probe kit has been tested under open ended line that measures air in room temperature (Figure 4b). Secondly, a shorting block has been connected to the end of the probe line that creates short circuit effect on the main microwave line (Figure 4c). Finally, a clean water tube is connected to the probe line under room temperature condition and calibrated by this reference liquid (Figure 4d). Moreover, since, dielectric characteristics of the water and the air are well known, measured values of these samples have been used to test the accuracy of the calibration.

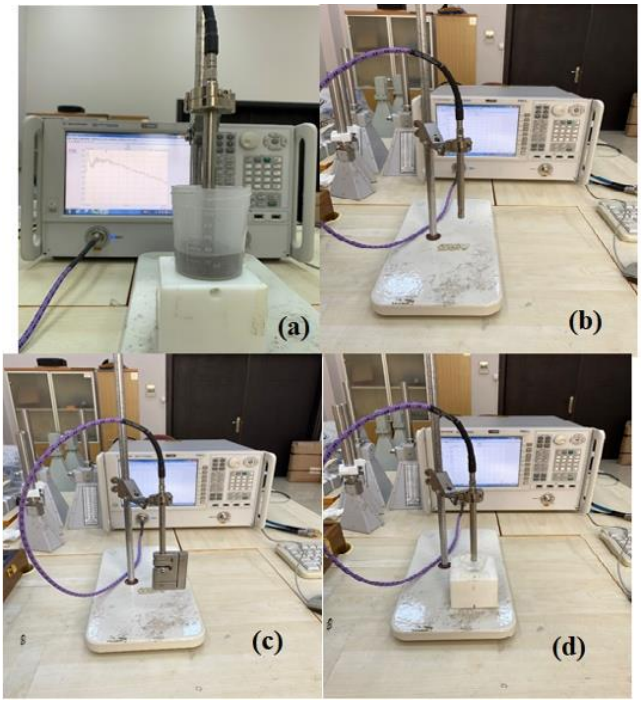

Figure 4. Complex dielectric parameter measurement setup for 1 GHz-20 GHz band (a) Calibration with respect to air (b) known load (c) pure water (d).

Furthermore, the measured real and the imaginary parts of the various shell samples are illustrated in Figure 5. The real parts permittivity of ds-shell, shell-600, shell-800, shell-1000 and shell-1200 are 3.6, 3.2, 2.2, 2.0 and 2.4 at center frequency of 10 GHz, respectively. Moreover, the imaginary parts of ds-shell, shell-600, shell-800, shell-1000 and shell-1200 are 0.9, 0.8, 0.35, 0.3 and 0.4 at center frequency 10 GHz, respectively. These differences are caused by the applied various heating temperatures. In addition, air has values of 1 for real and 0 for imaginary parts of the complex permittivity.

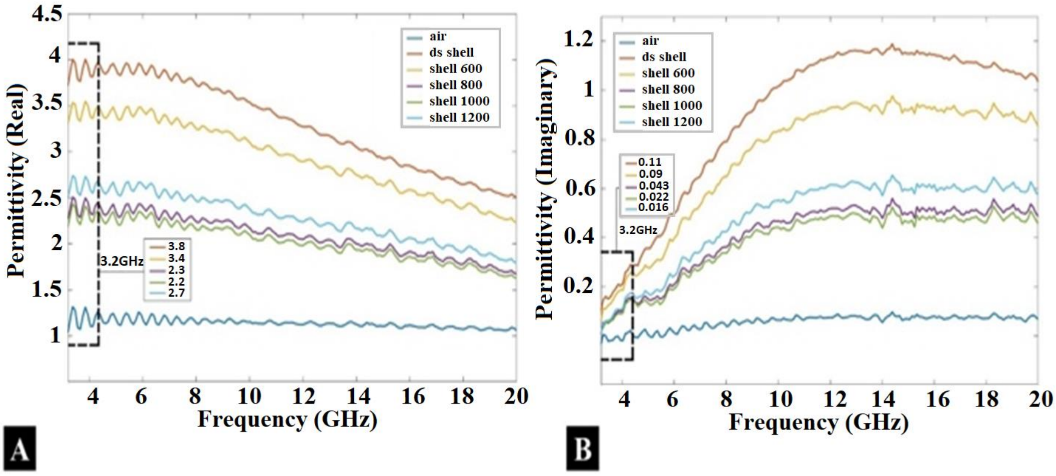

Figure 5. Real (a) and Imaginary (b) parts of measured Shell samples in frequency range of 3.2-20 GHz

According to the measurement values of the imaginary parts of relative permittivity results, especially except for ds shell sample, all the samples have very low imaginary part between 3.2-4 GHz frequency ranges. Due to these low values of losses (i.e. imaginary part of permittivity) and to form of powder, the samples under tests can be utilized as microwave laminate materials such as FR4 and some types of Rogers. The loss tangents of FR4 and Rogers 7880 are between 0.02-0.03 and 0.0009 for FR4 and Rogers 7880 laminates, respectively. It is well known that the prices of the laminates increase with respect to low losses characteristics at microwave applications especially for military technology. The proposed samples can be a good candidate for future organic laminate productions after effectively pressing the powders. In addition, the difference of real part of the permittivity for various samples can also give chance to fabricate various laminates with different dielectric constants for microwave device designers' areas. It can be seen from the figure that the real parts of the permittivities for ds-shell, shell-600, shell-800, shell-1000 and shell-1200 are 3.8, 3.4, 2.3, 2.2 and 2.7, respectively for 3.2 GHz (Table 1).

Table 1 The comparison of real and imaginary parts of samples with commercial substrates

Sample	Dielectric constant (Real) at 3.2 GHz	Dielectric constant (Imag) at 3.2 GHz
FR-4	4.3	0.1075
Roger 5880	2.2	0.00198
Ds-shell	3.8	0.11
Shell-600	3.4	0.09
Shell-800	2.3	0.043
Shell-1000	2.2	0.022
Shell-1200	2.7	0.016

One other microwave application area of the materials is radome design. In radome design, the important requirements are low losses of the structure in related frequency range, high impedance matching with free space and mechanical strength. As can be concluded from the measurement values, the measurement results of powders guarantee the low loss criteria. Besides, the samples with real part of permittivity around 2 also can provide impedance matching with free space. Hence, if the pressing of the powder is sufficient in terms of strength, the materials can be used in radome applications as a natural candidate.

In addition, the investigation of the samples with respect to change of temperature has been realized due to observe temperature dependency of the samples. As can be observed in Figure 6a, the temperature change results in alteration especially in real part of the permittivity. Hence, it can be concluded that the minimization of temperature change must be studied by adding additives for future studies.

Similarly, the complex permittivity of various spine materials has been measured as given in Figure 6b. The ds-spine, spine-600, spine-800, spine-1000 and spine-1200 has 4.9, 3.2, 2.2, 2.2 and 2.6 real permittivity values for 3.2 GHz center frequency, respectively. Nevertheless, these materials have imaginary part of the complex permittivity as follows for 3.2 GHz: 0.18, 0.08, 0.02, 0.02 and 0.05 respectively (Table 2). The focus of the study is especially on low loss characteristic of the spine powders same as for shell powder samples. This characteristic is important for many microwave applications. The proposed spines can be used as microwave laminates due to their ignorable values. In addition, to have different real parts of permittivity can provide alternative materials with various permittivity for microwave circuit designers. The imaginary parts of all samples are much lower with respect to widespread used laminate of FR4 in microwave applications. Since, the spines are natural and waste, this high technology application area provides a new field to utilize them. Besides this, the spines-based powders can be also used to construct novel organic radome due to have low losses as free space. The real part of the permittivity can be adjusted by temperature process as can be seen from Figure 6a. Hence, it is possible to provide required real part of permittivity after temperature process for both laminate and radome applications.

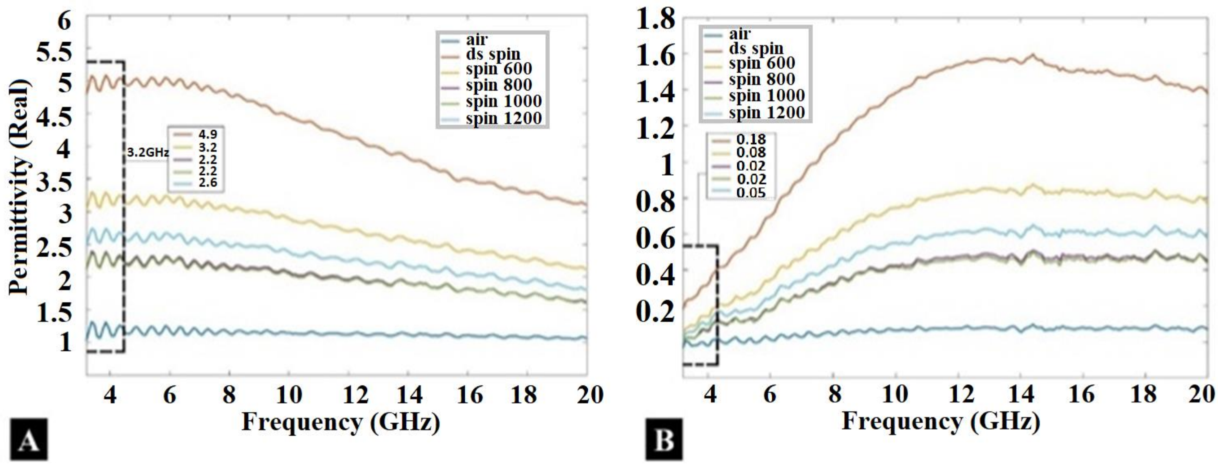

Figure 6. Real (a) and Imaginary (b) parts of measured spine samples in frequency range of 3.2-20 GHz

Table 2 The comparison of real and imaginary parts of samples with commercial substrates

Samples	Dielectric constant (Real) at 3.2 GHz	Dielectric constant (Imag) at 3.2 GHz
FR-4	4.3	0.1075
Roger 5880	2.2	0.00198
Ds-spine	4.9	0.18
Spine-600	3.2	0.08
Spine-800	2.2	0.02
Spine-1000	2.2	0.02
Spine-1200	2.6	0.05

The results obtained from complex permittivity measurements clearly shows that heated shell and spine powder materials are good candidates for microwave applications as substrate layer. These materials have low loss characteristics and can be used in many research applications as military radar, sensor, communication, and medical applications.

3 Conclusion

In this research, the microwave constitutive parameters of a biomaterial have been examined under two approaches in the 3.2-20 GHz band. These two materials are different type of powders which are shell and spins of invasive long-spined sea urchin. These powder samples from the bio-invaders were prepared and calcined at different temperatures as 600, 800, 1000 and 1200 C°. These biomaterials have been obtained because of grinding the shell and spines of sea urchin were turned into powder. The complex dielectric parameters of these classified biomaterials have been investigated in the 3.2-20 GHz frequency range with the open-ended coaxial probe method. The measured dielectric results clearly show that these biomaterials have a high usage potential in the microwave frequency region. The measured complex permittivity properties of the samples of shell and spines of invasive long-spined sea urchin have demonstrated that the samples can be utilized in development of high-quality microwave radomes with high impedance matching to air and low loss microwave substrates to design microwave circuits and resonators.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Similarity rate (iThenticate): %10

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